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AN EVALUATION OF AIRPLANE UPSET RECOVERY TRAINING PROGRAMS

ABSTRACT

Worldwide, aircraft loss-of-control (LoC) is the second leading cause of fatalities for transport category aircraft. Many of these situations were precipitated by aircraft upset events [1,2,3]. Some resulted from the interaction of the pilot with aircraft systems such as the autopilot or the flight control system. Others were due to external influences such as turbulence from other aircraft or atmospheric effects such as icing or windshear. The accidents resulting from these aircraft upset events are in some cases a result of the pilot's inability to make timely and correct control inputs when faced with one of the aforementioned extreme dynamic events.

In this paper, we will discuss the need for Upset Recovery Training (URT), describe innovative simulator training (ground and flight based) currently being offered to better equip pilots to deal with LoC situations, and present a research program designed to evaluate the effectiveness of these programs. Specifically, so-called Advanced Maneuvering Programs (AMP) adopted by the major United State (US) airlines and Veridian's URT program will be discussed. The proposed study is funded through the National Aeronautics and Space Administration (NASA) Aviation Safety Program (AvSP) and is supported by the Ames, Dryden, and Langley Research Centers.

BACKGROUND

When an aircraft accident occurs, the negative publicity erodes the public's perception of the safety. As a result of public concern about air safety, the Gore Commission was established to review the US air transportation safety record and make recommendations as to how to improve safety[1]. They learned that the commercial aircraft accident rate showed a pronounced decrease in the years following World War II but has now leveled at 0.3 accidents/million departures. It has remained nearly level since 1970[2]. Unfortunately, with the projected growth in air travel, the number of accidents per year is projected to double in the next decade (Figure 1).

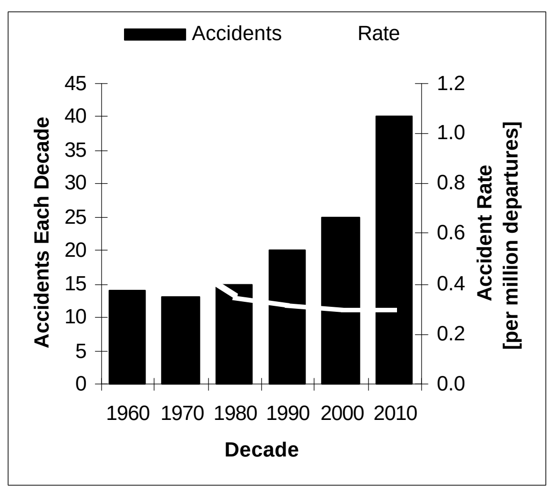

Figure 1 - Aircraft Accident Statistics[1]

The Clinton administration has put forth a goal to reduce the fatal aircraft accident rate by 80% within 10 years. In response to this stated goal, NASA in partnership with the US Federal Aviation Administration (FAA) sponsored a forum for a group of government, industry, and university partners to work on the Aviation Safety Investment Strategy Team (ASIST). The goal of ASIST was to identify key investment areas that given adequate support would show a high potential for reducing broad classes of accidents. One cornerstone of ASIST is a reduction in human errors through better training. The AvSP is the follow on to ASIST. It will earmark substantial funding over the next five years to support enabling technologies and innovative training in an effort to meet the ambitious ASIST goal. The common theme throughout the AvSP initiative is to break the "chain of events" that leads to an accident.

The accident data illustrates which causal factors contribute most to the accident rate worldwide. For the period 1959 –1996, the leading cause of fatal accidents was LoC (Figure 2). This holds true for both foreign and domestic carriers. When evaluating fatalities suffered as a result of airline accidents, data collected by NASA for the period 1987-1995 tells much the same story (Figure 3). Fatalities due to LoC total over 2,200, second only to nearly 2,300 fatalities caused by Controlled Flight Into Terrain (CFIT). What is compelling about this data is that all other causal factors taken together account for barely a third of the fatalities.

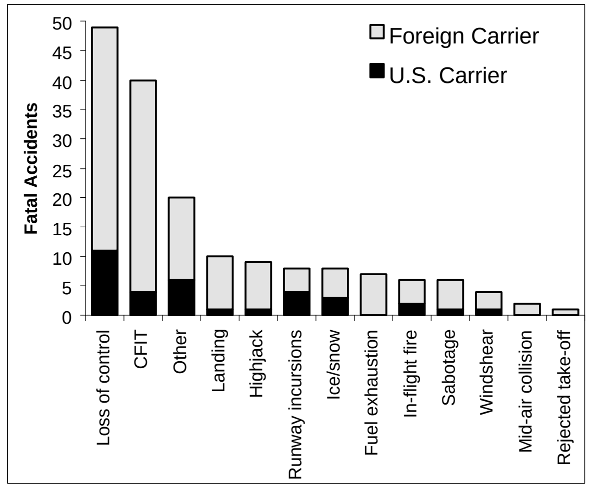

Figure 2 – Fatal Accidents of U.S. and Foreign Airlines 1959 To 1996(1)

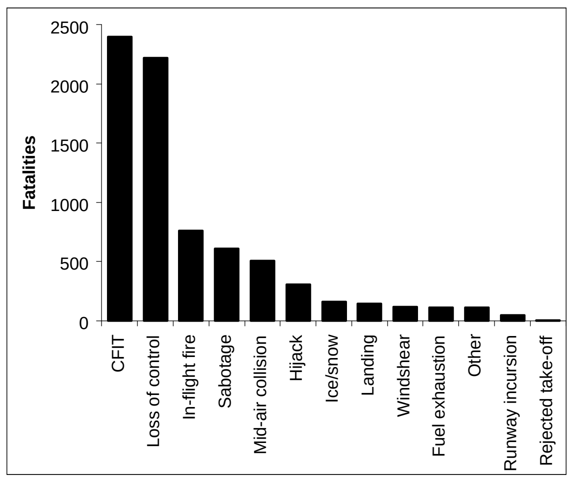

Figure 3 – Accident Fatalities World-Wide 1987 to 1995(4)

While the CFIT threat has been addressed through massive investments in technology, little has been done to reduce LoC accidents. This is partially due to difficulty in finding a solution. CFIT can be solved for the most part with technology. Recent advances, such as Enhanced Ground Proximity Warning Systems (EGPWS), and enhanced situation awareness cockpit displays have significantly reduced the risk of CFIT. Unfortunately, LoC can not be solved with technology alone. Meaningful reduction in the LoC accident rate will require advances in training techniques.

The chain of events leading to a LoC accident often begins with an aircraft upset event. An aircraft upset is defined as "an airplane unintentionally exceeding the flight parameters normally experienced in line operations or training. NASA Aviation Safety Reporting System (ASRS) data indicates for the period 1987-1995, nearly 300 upset events were reported by commercial pilots flying multi-engine turbojet aircraft [5]. The majority of these were environmentally induced. A lessor causal factor was aircraft control systems and control-logic malfunctions. (Figure 4). In all of these situations, the pilot must be able to successfully recover from the event to prevent the incident from becoming an accident.

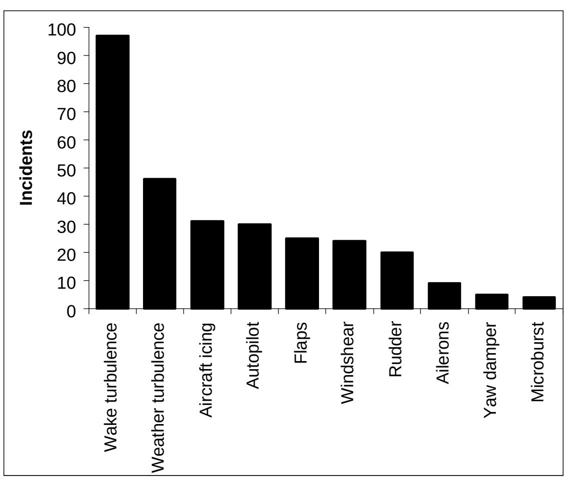

Figure 4 –Multiengine Turbojet Upset Incidents 1987 to 1995[5]

Historical Perspective on Training

In general, pilot training for commercial airline operations has evolved from primarily in-flight training to almost exclusively ground-based training due to the phenomenal growth in Ground-Based Simulation (GBS) and the increasing costs of flight operations. The cost to an airline for in-situ flight training is high since it includes not only the flight operations cost of the aircraft but also, the lost revenue or fixed capital cost of a dedicated airliner for training. This has reduced in-flight training to a minimum.

The US National Transportation Safety Board (NTSB) has issued numerous recommendations to the FAA regarding training of pilots. For example, NTSB Safety Recommendation A-72-152[6] directed the FAA to amend 14 CFR 61 and 121 to "…include a requirement for pilots to demonstrate their ability to recover from abnormal regimes of flight and unusual attitudes solely by reference to flight instruments. For maximum effectiveness, these demonstrations should be conducted in an appropriate flight simulator. Should existing or proposed simulators be incapable…the FAA [should] take appropriate measures to require that such existing or proposed simulators be replaced or modified to include such a capability."

The recent prevalence of accidents in which upset events may have been contributing factors has resulted in further action by the FAA. In August 1995, the FAA issued a bulletin that strongly suggested air carriers include in their flight training programs rare, potentially life-threatening events that could lead to LoC and an accident [7]. This type of training was termed Selected Event Training (SET). Its purpose is to broaden the standard training syllabus from common aircraft emergency and instrument operating procedures to those rare events such as recovery of the aircraft from extreme attitudes.

Although SET is not mandatory, most US domestic air carriers have voluntarily incorporated it into their curricula. These programs attempt to prepare pilots to cope with aircraft upset events. They range from classroom instruction only to classroom instruction integrated with GBS sessions. Two examples are American Airlines Advanced Aircraft Maneuvering Training [8] and United Airlines Advanced Maneuvers Training [9].

To date, no US airline includes in-flight training as part of their URT program. In fact, only routine operational training is accomplished in-flight and typically this is performed in service. As a consequence, the complete environment (the oral, visual, and acceleration cues) is never combined during the pilot's training since GBS training can only provide a portion of these critical flight cues. At issue is whether in-flight training will better equip pilots to deal with the highly dynamic nature of upset events.

As the need for URT for airline pilots was being voiced, it became clear that the In-Flight Simulation (IFS) aircraft operated by Veridian would be well suited to the URT mission. The value lies in their capability to perform maneuvers in the full-flight environment with the high level of repeatability needed for training while accurately duplicating the characteristics of transport aircraft, each with its own unique characteristics and potential failure modes.

URT PROGRAMS

The airlines with GBS and Veridian with IFS based URT have been instrumental in implementing directed pilot training to reduce the LoC accident rate. Consequently, these programs are being proposed as models for NASA's URT experiment.

We will now describe these programs and then briefly outline how their effectiveness will be evaluated. Of particular interest is what combination of training events (including classroom instruction, GBS, and IFS) best improves pilot performance when dealing with upset-induced LoC situations.

AIRLINE URT

These programs set out to improve flying skills of the pilots and their knowledge of upset causal factors. The courses are taught in conjunction with GBS sessions or as a stand-alone lecture series. Both American Airlines and United Airlines include training in the GBS.

Generally core subject areas include aerodynamics, unusual attitude recovery procedures, upset event causal factors, and the handling of automation.

In the aerodynamics discussion, terms that are typically not known in the general pilot population are defined. Also, more advanced concepts like the impact sweep angle has on dihedral effect are discussed. Here the emphasis is on imparting practical knowledge rather than on rigorous treatment of the subject.

Unusual attitude recovery typically focuses on situational awareness and emphasizes instrument recovery procedures. This involves the traditional actions of "pulling to the horizon using a sky pointer" and confirming aircraft attitude through multiple means. Generally, procedures are offered for recovery from "very" nose high/low attitudes. Most programs promote the use of bank angle (limited to 60°) to accelerate recovery from nose high conditions.

In discussing upset causal factors, both avoidance and recovery are covered. Emphasis is usually placed on atmospheric causes rather than aircrew/system anomalies. Atmospheric causes covered include microburst, wake turbulence, and mountain wave. System and aircrew anomalies include control malfunctions, engine failure, system failure (e.g. false stick shaker), and instrumentation/display malfunctions. Here again some advanced concepts such as static and dynamic stability, and how certain conditions can lead to a Pilot Induced Oscillation (PIO) are covered.

In many programs, automation dependence and the detrimental effect it can have on situational awareness are discussed. Here the idea that lower levels of automation should lower workload in a changing environment is presented. American Airlines recognizes that a cultural change may be necessary to stop attempts by pilots to operate at the highest levels of automation at all times[8].

VERIDIAN URT

Over the past two years Veridian has developed a training program that exposes pilots to unexpected LoC situations, lets them explore alternative control strategies, provides experience with extreme maneuvers, and teaches them how to verbalize controllability problems in order to better utilize crew resources. The content draws heavily on our experience in aircraft flying qualities research and test pilot training. However, the program is tailored to the non-engineer/non-test pilot. This avoids the need for a technical background.

In-Flight Simulation Historical Perspective

Since the development of the first IFS aircraft (US Navy F-4U) in 1948 by Veridian, IFS has gained wide acceptance as a necessary step in the design of new aircraft. Nearly every new aircraft developed by the US military from the X-15 to the F-22 has made use of IFS as a method to reduce risk and improve the design prior to first flight of the actual test vehicle. IFS has proven to be invaluable to these design teams in eliminating the questions raised during the GBS phase of development. Design teams have often found that GBS work, subsequent to IFS testing, is made more useful because the test pilot's GBS experience becomes "calibrated" to the flight environment.

A key advantage of IFS aircraft is they can replicate the handling characteristics of new aircraft designs or design concepts without the risk and cost of the actual prototype.

An extension of the IFS aircraft mission came about in 1960 when these airplanes began flying at the US Air Force (USAF) and Naval Test Pilot Schools for training. They proved ideally suited for this role in that they could be programmed to fly as many different airplanes on a single sortie.

Veridian currently operates a fleet of four IFS aircraft used for research and training (NC-131, NF-16D, LR24, and LR25). The two Learjets are primarily used in the training role (Figure 5). Their side-by-side seating and easily programmable system make them ideal flying classrooms.

Figure 5 - IFS Learjets

The simulation system in these aircraft is built around a fully programmable fly-by-wire flight control system (FCS). The training or evaluation pilot flies the aircraft through the programmable FCS while the safety pilot retains the "host" aircraft controls and control system.

The heart of the simulation system is a digital computer that uses a mathematical model of the simulated airplane to calculate its motions (Figure 6). By means of the FCS, the "host" IFS aircraft automatically follows the motions of the simulated aircraft.

Figure 6 - IFS Interior

An integral parameter-limit system and the presence of the safety pilot assure safety. In the event the simulated airplane cannot be controlled easily, the Safety Pilot disconnects the simulation system and takes over flying the host IFS aircraft with its requisite good flying qualities. The SP can terminate a potentially unsafe situation prior to its becoming a problem.

An example that illustrates the importance of the full motion cueing provided by IFS aircraft is a study funded by the USAF to qualify a Head-Up Display (HUD) as a primary flight reference display. An Unusual Attitude Recovery (UAR) was used as a key task to validate the HUD and its various formats. Objective and subjective evaluation data from this test showed that the GBS evaluations of critical flight displays in highly vertigo-inducing maneuvers were insufficient in comparison to the actual flight events [(10)]. From these results, the USAF Wright Laboratory as part of a cockpit display upgrade for military transports funded a follow-on study. In order to determine the pilot's situational awareness under instrument conditions with the new display, the IFS was programmed to be a C-141 transport and to automatically fly itself into several preset unusual attitudes. The subject pilot rode through the maneuvers with a blacked-out display to the desired upset entry point. The display was then turned on and the pilot given control of the aircraft by the computer in order to fly the recovery. This study again showed the critical need for full-flight cueing to generate the typical flight illusions of vertigo and spatial mis-orientation and thus, to accurately assess the suitability of a new instrument display suite for primary flight reference.

<u>Program Content</u>

This 2-day program consists of four hours of classroom instruction, and flights in an aerobatic aircraft and an IFS Learjet. The aerobatic aircraft serves as a confidence builder and allows pilots to experience extreme flight attitudes. The in-flight simulator, programmed to replicate the transport aircraft characteristics, introduces pilots to upsets, generic failures, and controllability problems. These are presented in a Line-Oriented Flight Training (LOFT) format.

The four hours of classroom instruction, supplemented with self-study training aids, are designed to enhance the pilots' understanding of upsets and teach effective recovery techniques. We begin with a review of the accident record, identifying causes of upsets, and use NTSB animations to illustrate the important points. Next we review aerodynamic fundamentals such as the impact of center-of-gravity shifts and high altitude (coffin corner). We explain why Dutch roll, adverse yaw, and dihedral effect due to wing sweep complicate recoveries. We discuss upset recovery strategies including how to minimize altitude loss when terrain clearance is critical, the effect angle-of-attack has on aircraft response, and what alternate control strategies are useful when critical aircraft controls are lost. Finally, we look at techniques to help mitigate the human-element of an upset. Self-study training aids (videos, literature, and desktop-computer flight simulation) fill the time between flights.

During flights in the aerobatic aircraft, an F-33C (aerobatic Beech Bonanza), pilots learn to control the excessive aircraft attitudes often encountered during upset events. This aircraft was chosen because it is an effective surrogate to the transport aircraft cockpit (Figure 7). The conventional side-by-side seating configuration, yoke control, and limited visibility (especially vertical visibility) are all representative. These coupled with limited performance, especially in the roll axis, make upset recoveries, and the limited aerobatic maneuvers more challenging. In particular, they learn just how difficult it can be to make full control inputs and to stay oriented with limited visibility. For these reasons, this aircraft is better suited to this training than a high performance aerobatic aircraft would be.

Figure 7 - F-33C Aerobatic Beech Bonanza

The training focuses on basic recovery techniques using standard aerobatic maneuvers. We use a combination of loops and rolls to illustrate all-attitude aircraft control. A stall-spin series focuses attention on a class of accidents caused by failure to break the stall during recovery. A g-awareness demo illustrates how to *max-perform* the aircraft. Finally, we let the trainee experience why a split-S is generally not the appropriate recovery maneuver.

The IFS Learjet lets the pilot safely experience a multitude of upset events including simulated control and system failures and atmospheric disturbances. This flight consists of demonstrations and LOFT. It begins with a hands-on demo of the aerodynamic concepts presented in class. During the LOFT, we give preprogrammed upset and let the trainee deal with the events by identifying the cause and determining an appropriate recovery strategy, including how to use alternate controls. The most important aspect of this training is experiencing LoC in an aircraft programmed to handle like a representative transport aircraft.

Anecdotal evidence from initial evaluations indicates that for the highly-dynamic maneuvers typically encountered during aircraft upsets, the combination of all flight cues (including acceleration) improves the training. For example, one Boeing 737 captain noted after IFS training that… "the greatest strength of the program is the capability of the In-Flight Simulator to safely create unannounced upset events in an actual jet aircraft… in addition, the g-forces, stress factor, sounds and fidelity of the In-Flight Simulator are far superior to what I have experienced in the most modern GBS… I could attempt upset recoveries in a jet aircraft; something for which I have been training for years, but never actually accomplished." (11)

URT EXPERIMENT

Veridian has been awarded a grant, "Airplane Upset Training Evaluation", by the NASA AvSP (NAS2-99070). The goal is to measure the improvements in pilot performance that can be gained by incorporating URT into traditional training programs.

The grant has three parts: 1) design an evaluation of current airplane upset training, 2) hold a workshop to review the proposed evaluation, and 3) provide in-flight airplane upset training for 8 subjects. Twenty-four people representing 15 different organizations attended the workshop. Another 75 people were sent the 3 workshop slides and the draft evaluation plan for comment. All but two provided comments. In all, 31 organizations (3 aircraft manufacturers, 13 airlines, 2 pilot associations, 2 air transport associations, 3 regulatory agencies, 4 pilot training companies, 3 research agencies, and the NTSB participated. On the basis of this workshop a revised study was designed.

The revised study is a between-subjects design with five groups. Each group is composed of eight, male, non-military, new-hire pilots from a single airline. The first group, “Untrained” is made up of pilots prior to the start of their training at the airline. These pilots have not had any aerobatic flight experience. The second group, “Untrained with Aerobatic Experience”, is made up of pilots prior to the start of their training at the airline but these pilots have had aerobatic experience. Aerobatic experience is defined as at least six-hours of training completing Aileron Roll, Barrel Roll, Chandelle, Cloverleaf, Cuban Eight, Immelmann, Lazy Eight, Loop, Split S, and Stall Turn maneuvers or experience performing in airshows or stunts in an aircraft with an FAA aerobatic waiver. The third group, “Simulator”, is made up of pilots who have started at the airline and have received airplane upset training in both ground school and in GBS. These pilots do not have any aerobatics training or experience. The fourth group, “Simulator with Aerobatic Experience”, have received the same training as group three but in addition have aerobatic flight experience as defined above. The fifth group, “In-flight”, is made up of pilots prior to the start of their training at the airline who receive in-flight airplane upset training using the Veridian IFS Learjet. This last group does not have any aerobatic experience as defined above.

The revised evaluation plan has been submitted to NASA for funding this fall.

The tasks used for evaluation have yet to be selected. The Precision Instrument Control Task (PICT) is an evaluation task used successfully in the past by Veridian. Some form of the PICT could be used for this evaluation.

The PICT consists of a series of level, descending, climbing, and decelerating turns separated by straight-and-level flight segments. The maneuver simulates representative portions of standard instrument departure routes, standard terminal arrival routines, and controller vectoring. The PICT provides a demanding piloting task that stresses the pilot's instrument crosscheck. The PICT is flown from directions issued by the experimenter using a canned script for aircraft heading, airspeed, altitude, and rate-of-climb commands mimicking Air Traffic Control vectors or an instructor pilot commands. (The PICT is a test of instrument flight skills, not of the memory.) The pilots are instructed to maintain precise flight path control and that their performance is graded.

For URT evaluation, a failure/upset would be introduced during the PICT. Based on ASRS incident data, the upset would include failures of autopilot, engine, gyro, INS, or yaw damper as well as a jammed yoke as well as atmospheric effects such as icing and turbulence.

Specific performance measures to evaluate training effectiveness are still being identified. Statistical comparison of the control and test group data will be conducted to show the benefit of the given training regime.

CONCLUSIONS

If the commercial aviation industry is to meet the challenge put forth to reduce the accident rate in a meaningful way, innovative training methodologies must be developed. A well-designed training program that includes both in-flight and ground-based training may well be the kind of innovation required.

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